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Two particle correlation measurements at PHENIX

T. Todoroki for the PHENIX Collaboration*

University of Tsukuba,Tsukuba, Ibaraki 305, Japan
RIKEN Nishina Center for Accelerator-Based Science, Wako, Saitama 351-0198, Japan

Abstract

Measurements of two particle azimuthal correlations in relativistic heavy ion collisions are useful tools to dissect the interplay between hard-scattered partons and hot dense medium. Correlations with trigger particle selection relative to second order event plane are sensitive to the path-length dependence of parton energy loss and to the influence of the medium on jet for high and intermediate transverse momenta pairs, respectively. To study the parton-medium coupling, it is also crucial to obtain correlations with rejection of contributions from higher harmonic flow. We present current results of second order event plane dependent correlations as well as correlations in which contributions from higher harmonic flow have been excluded in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV measured by PHENIX.

Keywords: PHENIX, heavy ion collisions, two particle correlations, higher-order flow harmonics

1. Higher harmonic event planes and flow

In previous understanding of relativistic heavy ion collisions, it has been assumed that the spatial geometry of the participant nucleons shows almond-like shapes and considered that the generated hot and dense medium mainly expands in the direction of short axis of almond-like shapes.

Recent studies with AMPT model simulations[1] and experimental measurements [2][3][4] revealed that, in addition to ellipticity, there are triangularity, squarity as well as higher-order deformation in the initial collision geometry originating from its fluctuations, giving thus rise to higher-order flow harmonics, i.e. anisotropy of particle productions relative to each harmonic event plane, over wide rapidity range. The effects due to fluctuations of initial collision geometry play an important roll for the understanding of space time evolution of the medium created in heavy ion collisions.

The amplitude of flow harmonics v_n is defined as

$$\frac{dN}{d\phi} \propto 1 + \sum_{n=1} 2v_n \cos(n(\phi - \Phi_n)),$$
$$v_n = \langle \cos(n(\phi - \Phi_n)) \rangle, (n = 1, 2, 3, ...), \quad (1)$$

where ϕ is the particle azimuthal angle and Φ_n is the direction of the nth harmonic event plane in transverse plane.

The v_n of hadrons within $|\eta| < 0.35$ is measured with the event planes determined in $1.0 < \eta < 2.8$ to ensure a sufficient pseudo-rapidity gap between particle and event planes to reduce non-flow correlations, such as those due to jet production.

*E-mail address: todoroki@rcf.rhic.bnl.gov

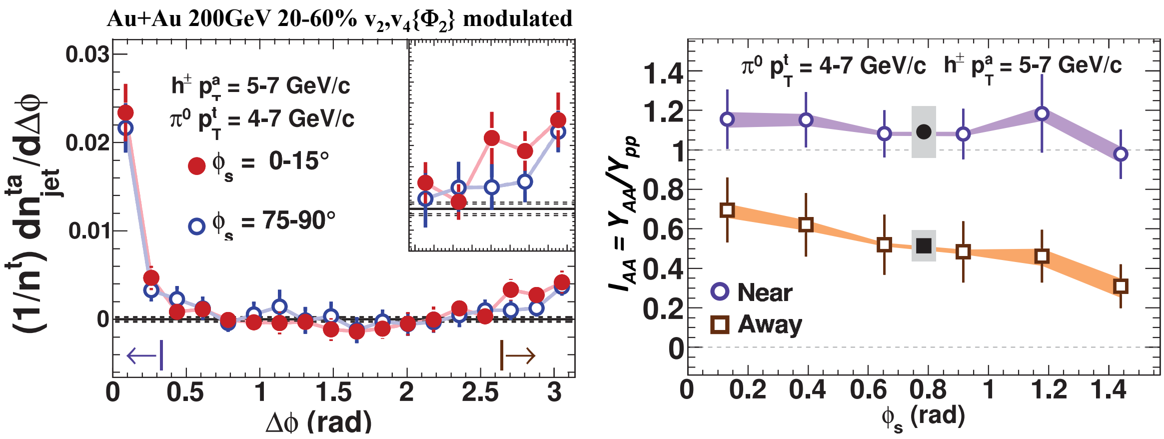

Figure 1: (Color online) π^0-hadron azimuthal correlations in Au+Au collisions at $\sqrt{s_{NN}}$ =200 GeV in centrality 20-60%[5]. Transverse momentum ranges are 4-7 GeV/c for trigger π^0 and 5-7 GeV/c for associated hadrons. Contributions from v_2 and $v_4(\Phi_2)$ are subtracted with ZYAM method. Left panel shows triggered correlations for the most in-plane and most out-of-plane intervals. Right panel shows the near and away side correlation yield as a functions of trigger particle angle relative to second order event plane $\phi_s = \phi^{trig} - \Phi_2$ normalized by correlation yield in $p + p$ collisions.

2. Two particle correlations

Two particle correlations are calculated by dividing the relative angular distributions of real event pairs with those from mixed events, and applying proper normalization:

$$C(\Delta\phi) = \frac{N^{real}_{pair}(\Delta\phi)}{N^{mix}_{pair}(\Delta\phi)} \frac{\int \Delta\phi N^{mix}_{pair}(\Delta\phi)}{\int \Delta\phi N^{real}_{pair}(\Delta\phi)}, \tag{2}$$

$$\Delta\phi = \phi^{asso.} - \phi^{trig.}, \tag{3}$$

where ϕ^{trig} is the trigger particle azimuthal angle and ϕ^{asso} is the associate particle one. Correlations have been measured with particles tracked at mid rapidity in the range $|\eta| < 0.35$ without rapidity gaps between trigger and associate particles. In the correlations, the contributions from jet survives, thus allowing us to study to the interplay between hard-scattered partons and medium.

In addition to inclusive trigger correlations, the study of two particle correlations with additional selection of the azimuthal angle between the trigger particle and the second order event plane provides a useful tool to control the path length which parton propagate. This studies produce measurements sensitive to the path-length dependence of parton energy loss with high momenta pairs and to the influence of medium effects with intermediate momenta pairs.

The correlations include the contributions from collective flow. The flow shapes can be estimated from experimentally measured event plane resolutions and the Fourier coefficients v_n. Their contribution is subtracted with the normalization factor determined by ZYAM method[6].

3. Results

3.1. Two-particle correlations versus event plane at high pt

The π^0-hadron correlations with neutral pions in the p_T range $4 < p_T^{\pi^0} < 7$ GeV/c as trigger particles and hadrons in the range $5 < p_T^{h^\pm} < 7$ GeV/c as associated particles are shown in the left panel of Fig. 1 for Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and in the centrality range 20-60%, where path length can be well controlled. Two sets of data points are shown, corresponding to different intervals of the angle between the trigger particle and the second order event plane.

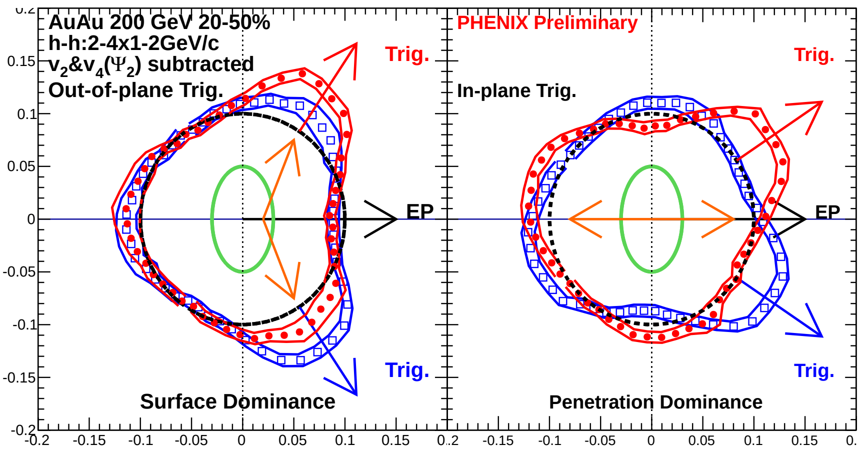

Figure 2: (Color online) Two particle charged hadron correlations in Au+Au collisions at $\sqrt{s_{NN}}$ =200 GeV in centrality 20-50%. Transverse momentum ranges are 2-4 GeV/c for trigger particles and 1-2GeV/c for associated ones. Contributions from v_2 and $v_4(\Phi_2)$ are subtracted with ZYAM method.

Right panel of Fig.1 shows the integrated yield in near and away side of triggered correlations, normalized to the yields in $p + p$ collisions as a functions of the relative angle between the trigger particle (π^0) and the second order event plane (Φ_2). Here the collective flow contributions from v_2 and $v_4(\Phi_2)$ harmonics are subtracted, while v_3 and v_4 are not subtracted. However the omission of higher v_n is not significant in correlation measurements with high momenta pairs, since the ratio of jet signal over flow contribution is large enough.

While the near side yield is consistent with the yield in $p + p$ collisions within the statistical and systematic uncertainties, the away side yield is significantly suppressed compared to $p + p$ collisions. The away side yield is monotonically decreasing as the angle between the trigger particle and the second order event plane increase, that is parton path length increases.

3.2. *Two-particle correlations versus event plane at intermediate p_T*

Fig.2 shows the hadron-hadron correlations in polar coordinates for trigger particle in $2 < p_T^{trig} < 4$ GeV/c and associated particles in $1 < p_T^{asso} < 2$ GeV/c in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, with the additional selection on the angle of the trigger particle with respect to the second order event plane. Also in this case contributions from v_2 and $v_4(\Phi_2)$ are subtracted from correlations with ZYAM method. In the left panel, the correlations are shown for the case of trigger particle in the out-of-plane region, while the case of in-plane trigger particle is shown in the right panel.

The open symbols (in blue) show the correlations where the trigger particle is selected in left side of event planes, while the closed symbols (in red) show the correlations where the trigger particle is selected in right side of event plane. The ellipse at the center (in green) represents the medium shape. The red, blue, and black arrows indicate the direction of the trigger particle and of the event plane, as well as orange arrows indicate the direction in which correlation yields are more pronounced.

Focusing on the away side shape of left-triggered correlations from event plane, the yield in longer path length tends to be larger than that in shorter path length side in the case of trigger particle exiting out-of-plane, while, for the case of trigger particle in the in-plane region, the yield in shorter path length side tends to be larger. Out-of-plane triggered correlations are dominated by surface emission of particles, however in-plane triggered correlations are overwhelmed by penetrating emissions. These observations indicate a non-monotonic behavior of the away side yield as a function of parton path length, which is inconsistent with the monotonic trends seen in high momenta pair correlations shown in Fig.1.

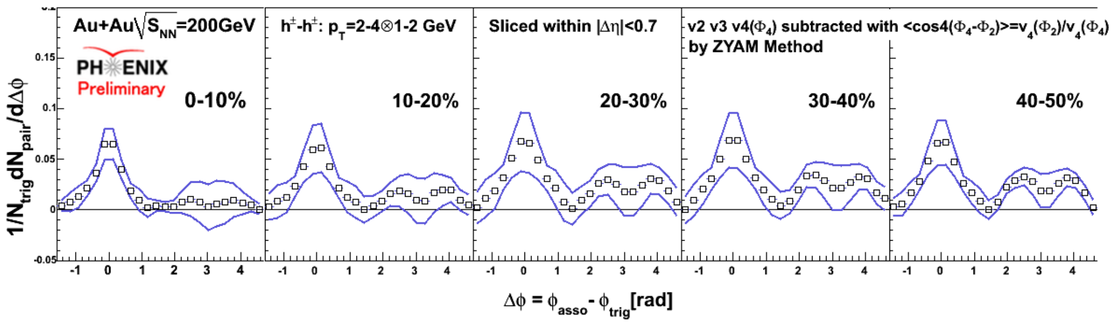

Figure 3: (Color online) Azimuthal correlations of two charged hadrons in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV in five centrality intervals in the range 0%-50%. Transverse momentum ranges are 2-4 GeV/c for trigger particles and 1-2GeV/c for associated ones. Contributions from v_2, v_3 and $v_4(\Phi_4)$ are subtracted with ZYAM method, considering the correlations between experimentally observed second and fourth order event planes defined as $\langle\cos 4(\Phi_2 - \Phi_4)\rangle = v_4(\Phi_2)/v_4(\Phi_4)$.

This non-monotonic behavior in triggered correlations is preserved even including v_3 terms to flow contribution subtraction. Since the correlation between second and third event planes is weak and contributions from v_3 is almost independent of the angle between the trigger particle and the second order event plane, and the same amplitude of contributions from v_3 is subtracted in any correlations with different trigger particle angle relative to second order event planes.

3.3. Two-particle correlations with v_n contribution subtractions

Fig.3 presents the hadron-hadron correlations for trigger particle in $2 < p_T^{trig} < 4$ GeV/c and associated particles in $1 < p_T^{asso} < 2$ GeV/c without selecting on the angle between the trigger particle and the event plane. The v_2, v_3 and v_4 are subtracted. The subtraction of contributions from v_3 and v_4 reduce $\cos 3\Delta\phi$ and $\cos 4\Delta\phi$ components in correlation functions, resulting in the disappearance of the away side correlation yield in most-central collisions, as seen in correlations with rapidity gap between pairs measured at the LHC[3][4]. However, away side yield and double humps remain even after the v_n contribution subtraction in mid-central collisions.

The remaining amplitude of v_3^{remain} which is estimated by the $\cos 3\Delta\phi$ components in flow subtracted correlations is roughly equivalent to the amplitude of already subtracted $v_3^{subtracted}$. It is difficult to explain away side double hump structure in mid-central collisions only with higher order flow harmonics v_n.

4. Summary

Two particle correlations with trigger particle selection relative to second order event plane have been measured at high and intermediate transverse momenta pairs. While away side yields in high momentum pair correlations shows a monotonic suppression as a function of path length, yields from two particle correlations at intermediate momentum show a non-monotonic behavior. Two particle correlations without selection on the trigger particle angle relative to the event plane and with subtraction of :the contribution from v_n flow coefficients show the disappearance of double hump structure in most-central collisions. However, the away side double hump structure is still present in mid-central collisions. It is difficult to explain the remaining away side double humps in mid-central collisions in the context of higher order flow harmonics.

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